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THE CLIMATE, SOILS, AND SOIL-PLANT RELATIONSHIPS OF AN AREA IN SOUTHWESTERN SASKATCHEWAN[1]

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INTRODUCTION

Differences in plant life between localities have probably been evident to man since his creation. These changes in the vegetation are usually associated with latitude, longitude and elevation. Within soil zones the changes are due to soil differences, topography and exposure.

In this paper, certain of the relationships that exist between plant communities and the soil, and climatic factors that influence their growth, are studied. The area lies within the mid-grass prairie formation in the southern part of the province of Saskatchewan, Canada.

REVIEW OF LITERATURE

Soil-plant relationships have long been recognized by the majority of workers in the fields of ecology, geobotany and pedology. Weaver (19) states "The fundamental relation in plant ecology is that reciprocal one between the plant and its habitat."

In many studies of soil-plant relationships, the effects of climate have not been assessed fully. However, to obtain a proper perspective of the habitat, the interdependency of soil, plant growth and climate must be considered and weighed, so that each contribution can be assessed according to its share.

Moss (9) mentions the striking correlations between the vegetation and the soil texture, being especially marked in sandy loam and other light soils. He also states that there is a close relationship between prairie vegetation and topography. Even the small variations of micro-relief were often found to be accompanied by pronounced differences in grass flora. Colvin and Eisenmenger (5) recognized two schools of thought regarding the major factors controlling plant distribution. One theory expounded contends that the chemical properties of the soil are the factors controlling plant distribution (Salisbury, 11), and (Silva, 16). The second supposition is that the physical properties of the soil are of primary importance in determining the presence or absence of a particular species (Shantz, 14). Bennett (1) states soil type exerts marked influence on vegetation characteristics, because of the various adaptive factors involved. Hicock (7) found no correlation between soils and vegetation. He attributes this to the fact that climate in some instances may compensate for the poverty of certain soil conditions.

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Tansley (17) has stated the problem where he mentions the difficulty in explaining the features of different kinds of soil, and of their relations to vegetation. He states: "Pedology is developing very rapidly and we are still largely ignorant of the exact ways in which different soils affect plants". Investigation of these questions leads straight to some of the most difficult problems of plant physiology and physical chemistry.

METHOD OF PROCEDURE

Existing soil survey maps (Mitchell *et al.*, 8), and information from previous surveys in connection with land use studies were used as a base for this study. Fifty sites supporting native vegetation were selected. These represented the five different soil textual classes in the area, namely, fine sandy loam, light loam, loam, clay loam and clay. All sites were located within a radius of fifty miles from Swift Current, Saskatchewan. As far as possible the sites selected were not overgrazed and in many cases a near climatic climax condition was observed. After the study had progressed sufficiently to warrant elimination, sixteen of the sites were discarded, as they were found unsuitable because of heterogeneous soil conditions and overgrazing. In many cases, the vegetal covers on the remaining sites had been changed in past years by grazing, mowing, burning, drainage and soil drifting, but the effects of these factors were indiscernible at the time the study was made.

Composite soil samples were collected from all sites. These were analysed for moisture equivalent, which gave a comparative figure for moisture retentivity of the soil. Wilting coefficient was determined by the indirect method based on that outlined by Work and Lewis (21). Determination of soil texture was made using the hydrometer method as outlined by Bouyoucos (2).

The vegetation was sampled by means of meter quadrats, and the point method as outlined by Clarke *et al.* (3).

NATURAL RESOURCES OF THE AREA

The area selected for the study lies within the Brown soil zone. This is very similar to the Brown soils of the United States. The Saskatchewan Haverhill association corresponds closely with the Scobey area of the United States. It occupies the short grass prairie (*Bouteloua-Stipa*) and the adjacent section of the mixed grass prairie (*Stipa-Bouteloua-Agropyron*) of Saskatchewan and Alberta at elevations of 1800 to 3800 feet. This is the most arid section of the province and is characterized by grassland vegetation, the absence of trees and the frequency of drought. The average precipitation ranges over different parts of this region from eleven to fifteen inches. The Brown soils have been developed over glacial moraine deposits which are essentially extremely variable in grade composition and topographic expression.

The surface area is undulating to rolling, broken by a number of valleys, escarpments, plateaux, and isolated hills. Other important physical features of the area include inter-moraine drainage basins of lakes Chaplin and Johnston, and the large areas of dune sand found in the Great Sand Hills west of Swift Current, Saskatchewan.

Although a large portion of the drainage is local, there is considerable spring run-off into the Saskatchewan River system through the Frenchman River along the southern section of the region. Local drainage is carried by shallow coulees and creeks into small lakes or sloughs, which are shallow and often saline. There is seldom any flow except during the spring run-off period.

The area under study has been covered by at least three advances of the Keewatin ice-sheet. Consequently, all soils are derived from the material deposited by the retreating and melting glaciers. Post-glacial climate has affected the soil development that followed glaciation. It has produced a soil that ranges in colour from light to greyish brown. The "A" horizon is up to six inches in depth, and covers a layer of calcium carbonate accumulation. The vegetational cover is a grassland climax, the dominants being both short and mid-growing species.

CLIMATE

Precipitation is the principal climatic factor that limits the growth of vegetation in the Brown soil zone. The area studied has a typical semi-arid climate and is situated in the centre of a broad ecotone with the mid-grass prairie to the east and north and the short-grass prairie to the west and south. As Swift Current, Saskatchewan, is located in approximately the middle of the study area, meteorological data obtained from the Dominion Experimental Station, Swift Current, were used. It was felt that this data would be comparable for the area used in this study. For a 28-year period, the total annual precipitation has amounted to 13.28 inches, with 7.04 inches falling during the growing season (Table 1). The annual precipitation, which fluctuates from year to year, shows no definite cycles of wet or dry. However, the tendency is for wet years to be very wet and dry years to be moderately dry.

Evaporation from a free water surface is 29.32 inches for the five summer months, giving a precipitation-evaporation ratio of 0.45. This high evaporation makes the rainfall relatively inefficient. According to Sanderson (12) the area studied has a semi-arid climate and an annual water deficiency of 8 to 10 inches. This water deficiency is large and imposes serious limitations on agriculture.

The snow, which accounts for 22.6 per cent of the annual precipitation, has an average depth of 30.1 inches. Winter thaws caused by chinook winds, which often melt much of the snow, occur occasionally, but lakes, sloughs and creeks remain frozen throughout the winter.

The area is characterized by a very wide range in temperatures between the extremes of summer and winter. The mean annual temperature is 38.4° F., the highest recorded temperature being 103° F. in June and July, and the lowest −55° F. in February. The winters are long and rigorous. The prevailing winds, which are from the southwest, are usually warmer than those from other directions, making the study area warmer and the temperature more variable than in the eastern and northern sections of the province. There are approximately 120 days between the last killing frost (29° F.) of the spring and the first killing frost of the fall.

TABLE 1.—METEOROLOGICAL DATA—DOMINION EXPERIMENTAL STATION, SWIFT CURRENT, SASK., 1922-1949 (28 YEARS)

Month	Temperature—° F.			Precipitation			Bright sun	Wind velocity	Evaporation
	Mean maximum	Mean minimum	Mean	Rain	Snow	Total precipitation			
				(inches)	(inches)	(inches)	(hours)	(hourly)	(inches)
January	18.9	0.2	9.5	0.04	5.8	0.62	93.8	7.4	—
February	21.7	2.8	12.3	0.00	4.7	0.47	122.1	7.7	—
March	33.5	15.3	24.4	0.05	4.9	0.54	169.8	8.1	—
April	52.2	29.0	40.6	0.58	2.3	0.81	205.4	8.5	—
May	64.6	39.0	51.8	1.53	0.4	1.57	236.6	8.7	5.54
June	70.8	47.3	59.0	2.81	0.0	2.81	227.6	7.5	5.79
July	80.4	52.4	66.4	1.85	0.0	1.85	301.8	6.2	7.43
August	77.4	49.1	63.2	1.74	0.0	1.74	256.6	6.2	6.41
September	65.9	39.8	52.8	1.03	0.7	1.10	194.7	6.7	4.15
October	54.2	29.7	41.9	0.53	1.8	0.71	159.6	7.3	—
November	35.0	16.1	25.5	0.07	4.7	0.54	96.7	7.5	—
December	23.0	4.8	13.9	0.04	4.8	0.52	79.7	7.6	—

In spring the native vegetation begins growth as soon as temperature conditions are favourable and maintains a rapid rate of growth until moisture supplies are exhausted, at which time the native grasses begin to dry and give the prairie a characteristic brown colour. Dry, hot winds in the summer have a marked desiccating effect on the soil and vegetation.

These climatic factors exert a definite influence upon soil development and native vegetation. Those factors of greatest importance are the relatively low precipitation, high evaporation, and extremes of temperature.

SOILS

The Brown soil zone comprises approximately 20,000,000 acres in Saskatchewan. It includes all of the shortgrass prairie formation, as well as parts of the mid-grass prairie formation in the eastern and northeastern sections of the zone. The soils are brown in colour as the result of the small amount of organic matter that is produced under the relatively low rainfall of the area. The lime layer, or horizon of calcium carbonate accumulation, is generally encountered eight to twenty inches below the surface.

The parent material of the soils studied is varied, but all of glacial origin. A large portion of the area has developed from undifferentiated boulder-clay deposits. This includes Haverhill light loam, loam, and clay loam. Others, including the most productive, have developed from clay deposits occupying the beds of former glacial lakes, namely, Sceptre heavy clay. The Hatton fine sandy loam has developed on sandy, glacial lake and alluvial deposits. The climate, and indirectly the soil, are probably the most important factors in determining the type of vegetation that will exist on a given soil. However, it has been observed that *Haplopappus armerioides* and *Mentzelia decapetala* occur apparently only in areas where the parent material is Bearpaw shale.

The light soils are usually well drained, the topography being classed as undulating to gently rolling. Stones are rare but gravelly sub-soils are common. In consequence of the sandy nature of the soil, the moisture-holding capacity is low. However, on the more level areas, the water table often is relatively high, permitting deep-rooted plants such as hoary sage *Artemisia cana* Pursh, to grow abundantly. Moisture penetration is also deeper in the lighter soils. Saline sloughs are common, the dominant salts being sulphate of calcium, magnesium and sodium. The lighter soils are characterized by a sparse population of the more drought-resistant plant species. Also, there is greater evidence of wind erosion. Figure 1 illustrates typical sandy soil topography.

The topography of the medium textured soils is gently rolling (Figure 2), and the vegetation of these soils is usually devoid of *Artemisia cana*. Drainage is good with the exception of a few shallow depressions. Stones are few to common, with more occurring in the steeper rolling phases. These soils have developed largely from undifferentiated glacial till.

The clay soils of the area are characterized by an almost flat topography and extremely few stones. Surface drainage is adequate but profile drainage is relatively slow owing to the high clay content of the soil.

The presence of an accumulated lime layer ($CaCO_3$) is characteristic of the soils under a grassland climax in areas of limited rainfall. This

accumulation generally takes place in the B horizon. The C horizon, which is composed of the parent material, is little affected by the soil-forming processes. Climate and vegetation, which are the most important of these processes, act only on the A and B horizons.

Some studies have been made in an effort to establish a definite relationship between the chemical composition of native plants and that of the soils on which they grow (Scott, 13), (Daniel and Harper, 6).

Table 2 shows the percentage of three important minerals found in the soil of the area studied. Until further work is done on the available nutrients in the soil and the actual requirements of plants, it is difficult to to state whether or not minerals are a limiting factor in the growth of native plants. At Manyberries, Alberta, it was found that barnyard manure spread over native pasture at the rate of fifteen tons to the acre increased the yield of grass, in some cases as much as four times. However, commercial fertilizers showed no beneficial effect. In most cases, water is such a dominating factor in controlling plant growth that it masks all others.

TABLE 2.—PER CENT TOTAL NITROGEN, PHOSPHORUS AND POTASSIUM ON UNCULTIVATED SURFACE SOILS

Soil texture	Per cent of nitrogen	Per cent of phosphorus	Per cent of potassium
Hatton fine sandy loam	0.17	0.05	1.48
Hatton light loam	0.20	0.04	1.70
Haverhill loam	0.20	0.06	1.60
Haverhill clay loam	0.23	0.05	1.69
Sceptre clay	0.24	0.08	1.76

Saskatchewan Soil Survey Report No. 12. (Mitchell *et al.*, 8).

VEGETATION

The vegetational cover of the area studied is a grassland climax. Scattered shrubs and small trees may grow in the vicinity of more favourable areas such as natural depressions, sloughs, and streams.

The area studied is within the mixed grass prairie as shown by the map (Figure 3). Perhaps a better name is the mid-grass prairie, as it is a mixture of the short and mid-grasses. The dominant grasses of the true tallgrass prairie do not appear in this association.

Weaver and Clements (20) considered the area to be a grassland climax with the mixed grass prairie, *Stipa-Bouteloua*, as an association and shortgrass, *Buchloe-Bouteloua*, a grazing disclimax rather than a true association as named earlier by Clements (4). Shantz (15) recognized the shortgrass formation, and the tallgrass formation which contained numerous associations, but he made no mention of the mixed grass prairie. It is the writer's contention that there are three grassland formations of the Great Plains prairie area of Canada, namely, the shortgrass (Figure 4), the mid-grass (Figure 5), and the tallgrass. In the shortgrass formation of Saskatchewan, the following associations are found: *Bouteloua-Carex*, *Bouteloua-Stipa*, *Bouteloua-Agropyron*, and an *Agropyron* consociation. From evidence

FIGURE 1. Typical sandy soil topography. This area has been heavily grazed. Notice the exposed clumps of *Opuntia polyacantha* Haw.

FIGURE 2. A loam soil illustrating the topography which is rolling, being a succession of knolls and depressions.

FIGURE 4. Good quality Herefords grazing on typical shortgrass prairie. The dominants are *Bouteloua gracilis* and *Stipa comata*.

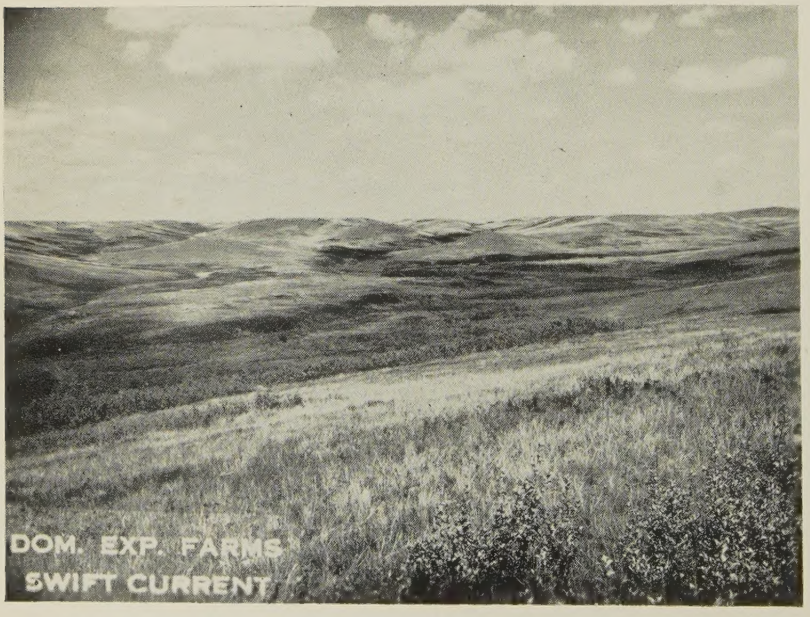

FIGURE 5. Typical mixed grass prairie. *Stipa comata*, *Agropyron Smithii*, and *Bouteloua gracilis* are the principal species.

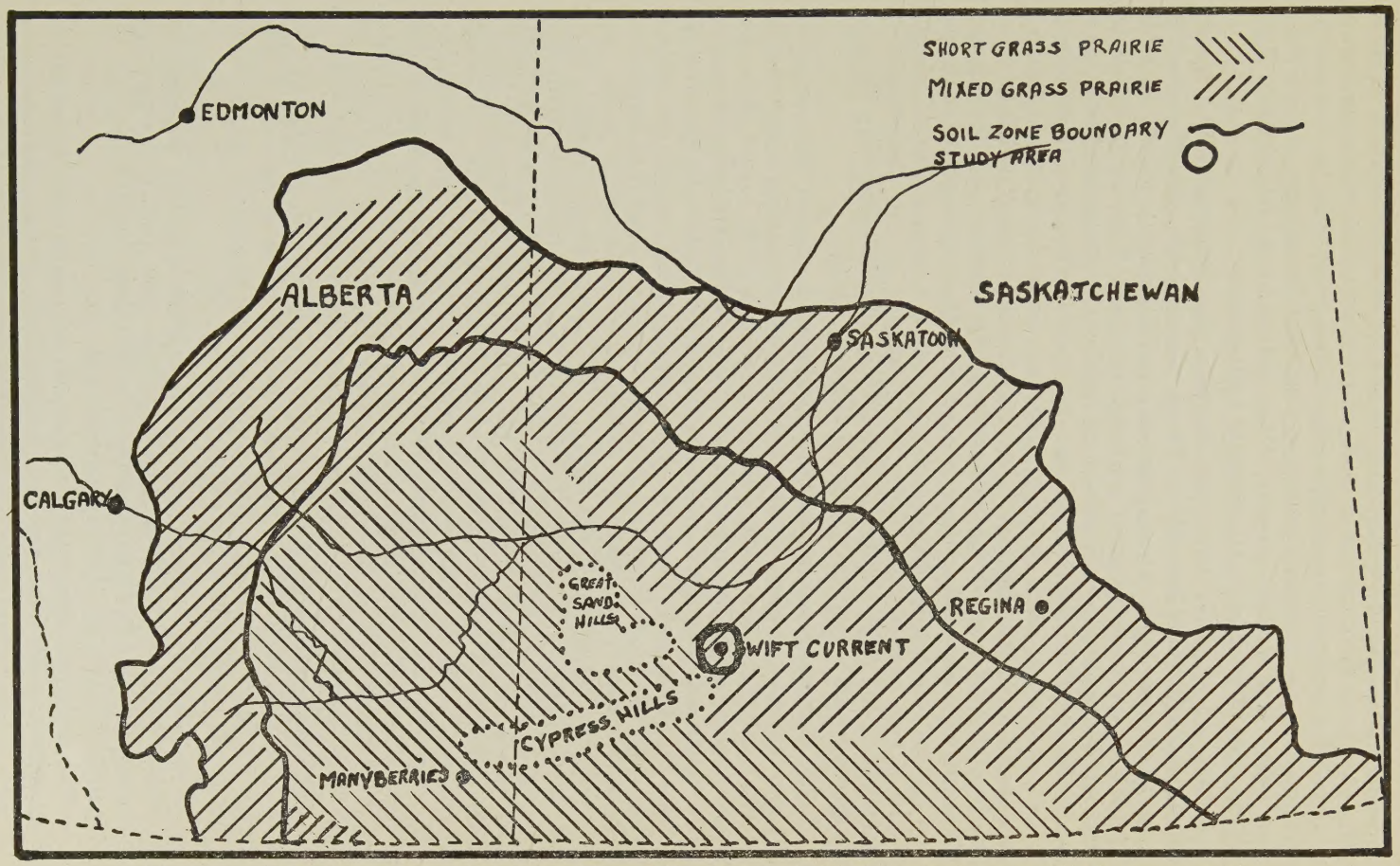

FIGURE 3. The location of the mid-grass prairie. Notice the boundaries of the area known as the shortgrass prairie.

exhibited in exclosures, which have been protected for eighteen years at Manyberries, Alberta, it would appear that, for southern Saskatchewan at least, a true shortgrass association exists rather than a disclimax caused by grazing. In the mid-grass formation of which the study area is part, there are several associations, namely, *Stipa-Bouteloua*, *Bouteloua-Stipa*, *Agropyron-Stipa viridula* and an *Agropyron* consociation.

In the mid-grasss formation the two main associations are *Stipa-Bouteloua* and *Bouteloua-Stipa*. These are very closely related. The balance between these two associations is so close that very little biotic or climatic disturbance is needed to change the cover from one to the other. In many areas a change may take place similar to that suggested by Weaver and Clements (20). That is, a climax stand of *Stipa-Bouteloua* or *Bouteloua-Stipa*, after a few years of overgrazing, may become a grazing disclimax dominated by *Carex eleocharis* Bailey, and *Bouteloua gracilis* (H.B.K.) Lag. In the mid-grass prairie area, the *Bouteloua-Stipa* association will not revert to a *Stipa-Bouteloua* association because of shallow soil together with the low annual rainfall and high evaporation rate. Consequently, it appears to be a true association. Under heavy grazing in the *Bouteloua-Stipa* association, the *Stipa* almost disappears and the *Bouteloua* may decrease or increase with a marked increase of *Carex eleocharis*.

The shortgrass association of the mixed-grass formation is characterized by two dominant grasses, *Bouteloua gracilis* which occupies over one-third of the total vegetative cover, and the speargrass *Stipa comata* Trin. and Rupr., which forms an integral part of the *Stipa-Bouteloua* association. Other commonly associated grasses are *Agropyron Smithii* Rydb., *Koeleria cristata* (L.) Pers., and *Poa secunda* Presl., which occupy varying percentages of the third total grass cover and are listed in their usual order of dominance. Grasses of lesser importance are *Calamagrostis montanensis* Scribn. and *Muhlenbergia cuspidata* (Torr.) Rydb. The most common sedge is *Carex eleocharis* Bailey, while *Carex filifolia* Nutt., is of frequent occurrence. Associated species are *Artemisia frigida* Willd., *Phlox Hoodii* Richards, *Malvastrum coccineum* (Pursh) A. Gray, *Pulsatilla ludoviciana* (Nutt.) Heller, *Androsace septentrionalis* L. var. *puberulenta* Rydb., *Gutierrezia diversifolia* Greene, and *Chrysopsis villosa* (Pursh) Nutt. Other species of less importance include *Atriplex Nuttallii* S. Wats. and *Opuntia polyacantha* Haw. *Selaginella densa* Rydb. occupies a large area, but exerts very little influence on the association. Of the shrubs, *Artemisia cana* is the most important with *Rosa Macounii* Greene playing a minor role except in sandy areas.

The short grasses are well adapted to the climatic conditions and light soils on which they exist. *Bouteloua gracilis* forms a very dense sod, competing keenly for all available moisture, and practically excluding all other grasss where moisture is in short supply.

The mid-grass association of the mixed grass formation is dominated by *Stipa comata* and *Bouteloua gracilis*. The growth conditions supporting this association are much more favourable than those conditions within the area dominated by the shortgrass association.

The mid-grass association is made up of two layers of vegetation. Such species as *Bouteloua gracilis* and *Carex eleocharis* form the lower layer beneath *Stipa comata*, *Agropyron Smithii*, and *Koeleria cristata*. In a

climax stand the competition between the two layers of vegetation seems to have reached a state suited to both. The short grasses possess the advantage of suffering less from evaporation and, because of their low growing nature, they are well able to withstand grazing. It is doubtful if lack of light is any disadvantage to the shorter growing plants in this area.

Associated grasses of the mid-grass association are *Stipa spartea* var. *curtiseta* Hitchc., *Agropyron trachycaulum* (Link.) Hitchc. var. *unilaterale* (Cassidy) Malte., *Agropyron dasystachym* (Hook.) Scribn., *Stipa viridula* Trin. and *Festuca scabrella* Torr. The latter may be found only in favoured places. The principal sedge is *Carex eleocharis*, while *Carex filifolia* and *Carex heliophila* may be found locally. In the lower areas, where moisture conditions are favourable to mesic species, *Carex atherodes* Spreng., and *Carex rostrata* Schw., may be found.

The shrubs found in this association are *Rosa Macounii*, *Symphoricarpos occidentalis* Hook., *Elaeagnus commutata* Bernh., and *Artemisia cana*. *Salix* spp. and *Populus tremuloides* Michx., occur under better than average moisture conditions, such as adjacent to sloughs, streams, and rivers.

The mid-grass association (*Stipa-Bouteloua*) is characterized by a large number of associated species which may be rare or abundant, depending on conditions. A few of the more important ones are: *Artemisia frigida*, *Phlox Hoodii*, *Malvastum coccineum*, *Pulsatilla ludoviciana*, *Liatris punctata* Hook., *Haplopappus spinulosus* (Pursh.) D.C., *Selaginella densa*, *Solidago* spp., *Gutierrezia diversifolia*, *Glycyrrhiza lepidota* (Nutt.) Pursh., *Eurotia lanata*, *Atriplex Nuttallii*, *Thermopsis rhombifolia* (Nutt.) Richards, *Astragalus pectinatus* (Wood) Dougl., *Chrysopsis villosa*, *Lydodesmia juncea* (Pursh.) D. Don., and *Androsace septentrionalis* var. *puberulenta*.

The principal life forms are the shortgrasses and the mid-grasses. These exist on all the sites studied but in various proportions of the total vegetational cover. The perennial forbs exist throughout the area with a larger proportion in evidence on the loam soils and a comparatively few on heavy clay. *Artemisia frigida* is the most common forb and can be found over the entire area. In many cases it serves as an indicator of overgrazing.

Productivity of the grasslands increases from the lighter soils to the heavier soils. The density of the grass cover shows the reverse trend (Table 3). The explanation is due to the difference in forage composition, palatability of the species, and their growth habits. For example, *Bouteloua gracilis*, which makes up over fifty per cent of the total grass cover on fine sandy loam, is very palatable, but its low-growing, mat-forming habit makes little of it available for live stock, with the possible exception of sheep.

To illustrate further, a 100 per cent density stand of *Stipa comata*, which is used as a standard for establishing yields (*Clarke et al*, 3) has been calculated to produce 5000 pounds per acre, while a 100 per cent density stand of *Bouteloua gracilis* yields only 1600 pounds per acre, or 0.31 *Stipa* equivalents. Consequently, the lighter soils which have a high percentage of *Bouteloua gracilis* yield less because the dominant grass. *Bouteloua gracilis* only yields approximately one-third of that of *Stipa comata*, which is the dominant on the medium textured soils, and only one-quarter as much as *Agropyron Smithii* which dominates the heavier soils.

TABLE 3.—THE YIELD AND PER CENT COVER OF GRASSES AND SEDGES, AS DETERMINED BY THE POINT METHOD, FOR FIVE SOIL TEXTURE CLASSES

Soil texture	Density of grass cover in per cent	Estimated yield in lb. per acre using point yield method
Fine sandy loam	13.16	302*
Light loam	13.27	329
Loam	11.52	448
Clay loam	11.19	371
Heavy clay	6.91	452

* Method used in determining yield described by Clarke *et al.* (3).

RESULTS

Vegetation has been used to indicate land suitable for agricultural purposes, ground water, and recently, as a geophysical instrument (Rankama, 10), to detect the presence of certain ores. This has been possible by studying the soil-plant-climate relationships as they exist. It is obvious that vegetation, if correctly interpreted, will answer many questions regarding the soil and climatic conditions of the region.

In a study of this kind dealing with soil-plant relationships, climate undoubtedly confuses the issue. The interaction of vegetation and climate has greatly modified the earth's surface, so that now we have many soils formed from various parent materials differing in colour, texture and structure. This has led to a close correlation between the soil and the vegetation which it supports. However, for a small area such as that used for the study, no correlation appeared to exist between the parent material of the soil and the vegetation.

To simplify the problem, the climatic data as presented earlier are assumed to be the same over the area studied. Making this assumption, the problem then becomes a soil-plant relationship study. However, soil moisture must be considered, although it is an indirect factor dependent on the soil texture which determines the moisture-holding capacity of any particular soil. Moisture may be concentrated in low areas due to topography, but as these areas only confuse the problem they were avoided. Very little is known at present of the water requirements of native plants or their physiology. Until more is known it is almost impossible to say whether a plant grows on a certain area because of local moisture conditions, or because of soil texture, or whether it is a combination of both. Because climatic data could not be obtained for each site they have been omitted as a variable with the knowledge that the omission may be the source of considerable error. Soil under this condition then becomes the most important factor controlling plant growth. The major differences in soils are caused primarily by the method of deposition, the nature of the parent material, and soil evolution. These differences are evident in the results of mechanical analysis, moisture equivalent, and wilting coefficient tests. Table 4 summarizes the data. From Table 4 it is seen that the lightest soil, fine sandy loam, contains a high percentage of sand and a relatively low amount of clay particles. Likewise, the moisture equivalent and the wilt-

TABLE 4.—PROPERTIES OF VIRGIN SOILS IN THE BROWN SOIL ZONE OF SASKATCHEWAN EXPRESSED IN PER CENT

Soil	Moisture equivalent		Wilting coefficient		Mechanical analysis					
					0–6 inches					
	0–6 inches		0–6 inches		Range			Average		
	Range	Average	Range	Average	Sand	Silt	Clay	Sand	Silt	Clay
Fine sandy loam	7.19 to 18.54	11.25	3.27 to 6.50	4.40	49.39 80.37	11.41 40.29	7.81 11.42	67.22	23.09	9.83
Light loam	18.15 to 28.94	20.59	6.42 to 10.31	8.31	53.25 77.15	14.96 29.08	7.89 18.76	58.69	20.89	19.61
Loam	17.12 to 24.41	21.06	6.35 to 10.87	8.05	40.81 47.01	35.90 41.35	14.58 19.60	43.81	38.08	18.77
Clay	21.55 to 35.45	27.04	7.84 to 15.27	10.12	20.40 44.13	29.44 50.70	22.86 48.40	35.38	37.33	27.34
Heavy clay	36.03 to 46.88	42.66	17.55 to 20.15	19.39	11.98 15.72	16.60 24.12	60.26 68.20	14.61	21.42	63.98

ing coefficients are low. As the clay content increases and the percentage of sand decreases, the soils are able to hold more moisture as indicated by the increase in the moisture equivalent and the wilting coefficient.

Clay contains a large percentage of particles of colloidal dimensions which naturally exhibit the properties of colloidal systems. One of these properties is the retention of water by imbibition, whereas silt and sand particles hold water only on their surfaces.

Theoretically, a clay soil should be able to support a more mesic type of vegetation than any of the soils studied. In sand there exist many mesic plants, almost all of which are deep-rooted, while shallow plants are unable to obtain moisture because of the rapid percolation of precipitation.

Because of the colloidal properties of the clay particles in heavy clay soils, many grasses seem unable to live. The swelling and shrinking of the clay particles causes the soil to crack. This cracking is very characteristic of heavy clay soils and appears to be detrimental to the root systems of bunch-grasses. In the case of *Agropyron Smithii*, which is rhizomatous, the tearing action only serves to separate young plants from the mother plant rather than destroying the crown and exposing many of the roots, as is apparently the case with *Stipa comata* and *Bouteloua gracilis*. However, there may be a competitive factor related to soil moisture that is at present not recognized.

In Table 5 the dominant grasses for the heavy clay soils are shown to be *Agropyron Smithii* and *Stipa viridula*. If grazing takes place the decrease in *Stipa viridula* is very marked. The dominant forbs of heavy clay soils are *Phlox Hoodii*, *Artemisia frigida*, and *Eurotia lanata*, in this order.

Table 6 shows clearly the close positive correlation between *Agropyron Smithii* and the clay content of the soil. From Table 5 it is evident that *Stipa viridula* is also correlated with clay content. *Bouteloua gracilis* tends to decrease as clay content increases (Table 5). Consequently, on the sandy soils, *Bouteloua gracilis* occupies over a third of the total grass cover, and in some instances as much as ninety per cent. *Stipa comata* and *Koeleria cristata* are present on all soil textures and show no apparent correlation with the percentage of clay present. From visual observation, this is true of *Koeleria cristata*. However, *Stipa comata* is generally the dominant grass on loam soils, but it is usually absent from the heavy clays. Often biotic or climatic factors make *Bouteloua gracilis* co-dominant on the lighter soils but *stipa comata* is often the dominant grass on newly stabilized dune sand areas. In this study pure sand has been disregarded because of its unstabilized nature. Other grasses of minor importance are *Stipa spartea* var. *curtiseta* which appears to reach its maximum development on loam soils; *Calamagrostis montanensis* which is equally distributed over the various soil types with the exception of heavy clay; *Muhlenbergia cuspidata* which usually indicates eroded slopes and hilltops; *Calomovilfa longifolia* (Hook.) Scribn. which is almost exclusively a sand plant; and *Poa secunda* and *Avena Hookerii*.

Of the forbs, *Artemisia cana* is the only one in this area that might be used as a soil indicator. While it occurs on all soil textures, it reaches its maximum development on light, well drained soils. *Selaginella densa*

TABLE 5.—CORRELATION OF NATIVE FLORA TO SOIL TEXTURE IN THE BROWN SOIL ZONE
SPECIES EXPRESSED IN PER CENT DENSITY OF TOTAL GROUND COVER

	Fine sandy loam	Light loam	Loam	Clay loam	Heavy clay
Grasses and sedges:					
Bouteloua gracilis	9.50	7.51	3.48	3.55	0.00
Stipa comata	2.02	2.22	3.49	3.01	0.00
Koeleria cristata	0.20	0.31	0.86	0.63	0.62
Agropyron Smithii	0.34	0.86	1.01	0.94	4.55
Stipa spartea var. curtiseta	0.05	0.18	0.72	0.42	0.07
Poa secunda	0.04	0.06	0.23	0.46	0.00
Muhlenbergia cuspidata	0.00	0.00	0.03	0.00	0.00
Calamagrostis montanensis	0.01	0.02	0.04	0.01	0.00
Stipa viridula	0.00	0.00	0.00	0.09	1.95
Avena Hookerii	0.00	0.00	0.00	0.01	0.00
Calamovilfa longifolia	0.04	0.00	0.00	0.00	0.00
Carex filifolia	0.17	0.12	0.12	0.17	0.00
Carex heliophila	0.00	0.00	0.13	0.11	0.00
Carex eleocharis	1.00	1.95	1.78	1.78	0.48
Per cent density total grasses and sedges	13.37	13.23	11.50	11.18	7.67
Forbs:					
Selaginella densa	8.70	6.41	5.13	4.20	0.00
Artemisia frigida	2.01	0.93	0.91	0.84	0.36
Phlox Hoodii	0.13	0.51	0.29	0.36	0.58
Artemisia cana	0.80	0.12	0.30	0.00	0.00
Eurotia lanata	0.00	0.00	0.00	0.00	0.15
Rosa Macounii	0.16	0.03	0.08	0.03	0.00
Number of sites	4	5	7	12	6

TABLE 6.—CORRELATION COEFFICIENTS FOR FOUR GRASSES WITH CLAY CONTENT

Variates Per cent clay in soil and grass cover in percentage	Correlation coefficient	Required for significance		Remarks
		One per cent level	Five per cent level	
Per cent clay and *Stipa comata**	0.109	0.478	0.374	Not significant
Per cent clay and *Koeleria cristata*	0.178	0.418	0.325	Not significant
Per clay clay and *Bouteloua gracilis*	−0.458	0.478	0.374	Significant
Per cent clay and *Agropyron Smithii*	0.895	0.418	0.325	Highly significant

* Two pairs of variates.

represents a large percentage of the total vegetation cover on all soils except heavy clay. The dominant forb for the area is *Artemsia frigida*, which appears in various proportions on all soil textures. It does not appear to be correlated with texture, and dense stands are indicative of an overgrazed condition in the northern Great Plains area. *Phlox Hoodii*, *Malvastrum coccineum*, *Haplopappus spinulosus*, and *Rosa Macounii* are common forbs of the area.

Table 5 presents a summary of the data that were collected during the study. The correlations as established are fairly evident from these data.

CONCLUSIONS

The correlation that exists between soils and vegetation is difficult to analyse because of the effects of climate. For this paper, climatic conditions have been assumed to be similar over the study area.

A close correlation was found to exist between *Agropyron Smithii* and per cent clay content of the soil. Consequently, soils possessing sixty per cent of clay and over were dominated by *Agropyron Smithii* and *Stipa viridula*. These grasses are indicative of clay soils or, more truly, of soil moisture conditions associated with clay.

Bouteloua gracilis and per cent clay in the soil showed a significant negative correlation. *Koeleria cristata* and *Stipa comata* showed no significant correlation with per cent clay content of the soil.

On loam soils, however, *Stipa comata* appears to be the dominant grass, yielding in the lighter soils to *Bouteloua gracilis* as the dominant, and in the heavier soils to *Agropyron Smithii*.

It is believed from information obtained during this study that there is a definite correlation between soil, plants, and climate. Much work to date, however, has been based on visual analysis which appears to be true for large areas, e.g., the shortgrass formation or the mid-grass formation. However, in small areas where more intensive study is possible, it appears that many correlations based on visual analysis are not statistically sound. For example, *Stipa comata* seems dominant on loam soils and yet there is no significant correlation between *Stipa comata* and the per cent clay content of the soil.

It is generally conceded, for a limited area at least, that much can be determined about the vegetation by examining the soil. This usually gives a good indication of climatic conditions that exist and the type of vegetation that would persist under the existing conditions of climate and soil.

Some plants may be used as indicators. *Artemisia cana* in most instances indicates a light well drained soil. *Eurotia lanata* is most prevalent on the heavier soils, while *Rosa Macounii*, where very abundant, indicates sandy soil recently stabilized. Of the grasses, *Agropyron Smithii* indicates soils heavy in texture with high water holding capacity, while *Bouteloua gracilis* is more prevalent on light textured soils. *Distichlis stricta* (Torr.) Rydb. indicates soils high in salt concentrations, while *Calamovilfa longifolia* and *Oryzopsis hymenoides* (Roem. & Schult.) Ricker indicate sand.

It is evident from the information obtained and the data that are available that more intensive work is needed in the field of soil, plant, and climate relationships.

SUMMARY

The approximate centre of the area studied is Swift Current, Saskatchewan. Of the total area, approximately sixty per cent is under cultivation. Of the remainder, two per cent is abandoned land, dominated by perennial and annual weeds, and thirty-five to forty per cent is native sod.

The climate is classified as semi-arid with a precipitation-evaporation ratio of 0.45. The highest rainfall occurs during the month of June. Great extremes of temperature characterize the area, with a total variation of over 150 degrees, and a frost-free period of approximately 120 days.

Composite soil samples were collected and analysed from all sites selected. Mechanical analysis, moisture equivalent, and wilting coefficient were obtained. Close correlation between the size of soil particles and the moisture factors is shown.

The vegetation of the region is described. This is comprised mainly of the grasses of the mid-grass formation, made up of several associations, namely, *Stipa-Bouteloua*, *Bouteloua-Stipa*, *Agropyron-Stipa*, and an *Agropyron* consociation. For the most part, the soils of the zone are characterized by light-brown coloured surface soils and a layer of lime ($CaCO_3$) accumulation relatively close to the surface.

The mineral elements of the soil do not appear to be limiting factors of plant growth on the area, although responses have been obtained by the use of manure. To date, however, there is little, if any, information on the mineral requirements of native plants in the Brown soil zone.

Climatic conditions throughout the area are assumed to be the same; however, soil texture which indirectly controls available moisture, is definitely correlated with the dominant grasses. A highly significant correlation was found between *Agropyron Smithii* and per cent clay content of the soil; and a significant negative correlation was observed between *Bouteloua gracilis* and the per cent of clay. However, no correlation was found between *Koeleria cristata* or *Stipa comata* and the per cent clay content of the soil.

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FACTORS IN RELATION TO TUBER QUALITY IN POTATOES

I. PENETRATION FORCE AND ELECTRICAL RESISTANCE[1]

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INTRODUCTION

The Irish potato (*Solanum tuberosum* Linn.) has been the subject of extensive tests of a clinical nature to determine quality for human food and other uses. The popular and very important nature of the vegetable has resulted in great interest in such "quality" tests; and in recent years certain of the tests have been used rather widely by plant breeders in order to get approximate starch content at an early stage in the development of promising seedlings.

Certain disadvantages of (1) panel judging of cooked tubers, (2) specific gravity of tubers, (3) alcohol tests and (4) quantitative starch determination, have led to attempts by at least two workers [Dallyn (5) and Turnquist (11)] to determine the feasibility of other means of measuring the density of potato tubers, or to measure some factor other than density that might be related as directly to tuber density as the latter is to starch content (3, 4, 7). Bewell (2) and Smith and Nash (10) have demonstrated a high correlation between mealiness and dry matter content and Rinear (9) has shown that dry mealy potatoes are preferred by 71 per cent of 1,653 consumers. It might also be of interest to note that in his survey by Rinear, 0.89 per cent of the consumers preferred watery or moist potatoes and only 0.6 per cent mentioned flavour as a quality criterion.

According to Gilmore (6) potato tuber dry matter content may vary rather widely (21.1 per cent to 27.2 per cent) within a variety, but other investigators (1, 3, 5) have shown that even wider variability is encountered between varieties. This indicates that, although a fairly large number of tubers of any one variety must be used in a test to ensure a representative sample, nevertheless any test that will measure tuber density, or correlated factors, can be used to separate one variety from another in this characteristic.

This paper discusses two attempts to secure results similar to those achieved by the well-known brine immersion tests, based upon tests that are less time-consuming or that require less cumbersome equipment.

EXPERIMENT 1 (Penetration Force Trials)

For many years maturity in tree fruits had been estimated by means of a "pressure gauge" that measures flesh firmness. It seems reasonable to assume that tubers of different density should differ in their resistance to an applied force. If such a test proved to offer a reliable guide to tuber density, it would be quick and convenient and would do little damage to tubers that were desired for other tests or for seed purposes. The value of such a test would be proved if a significant correlation between "penetration force" and density could be established, not only within a variety but regardless of variety.

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[2] Associate Professor of Horticulture.
[3] Agricultural Research Officer, Canada Department of Agriculture, University of Alberta.

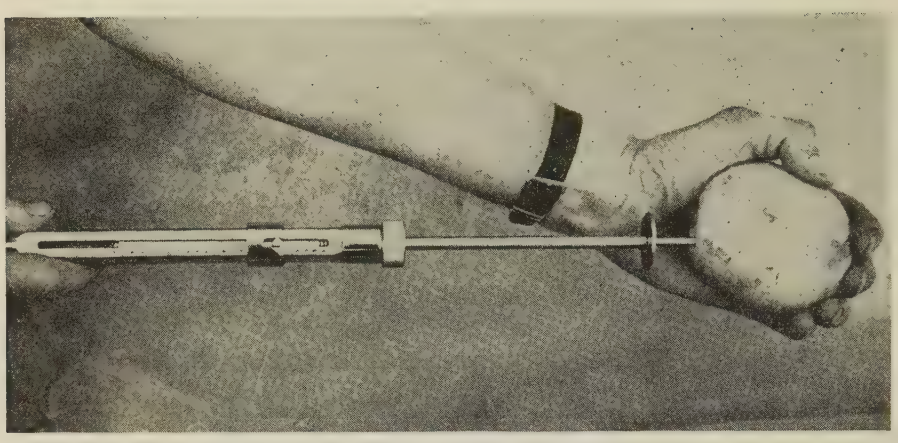

FIGURE 1. Method of using the pressure tester for penetration of potato tubers. The force exerted is measured directly in lb. pressure.

Materials and Methods

Potato tubers, the density of which has been determined by immersion in brine solution of known specific gravity, were selected at random from ten different varieties. A Ballauf Pressure Tester, designed for testing maturity, was fitted with a specially adapted plunger of 5 mm. diameter. The penetration apparatus is shown in Figure 1.

The plunger was forced into tubers of uniform size to a depth of 34 mm., care being taken to avoid regions at eyes, where cortical thickness variations would be encountered. Preliminary tests showed that the removal of the skin did not influence the readings, so no tuber paring was done in the test reported here. Seven penetrations were made on each tuber, and these readings were averaged to give a "mean force" record for each tuber.

Results

The results of a total of 196 penetration readings are summarized in Table 1.

TABLE 1.—PENETRATION FORCE READINGS ON POTATO TUBERS OF SEVERAL DENSITIES

Specific gravity classes	No. of tubers tested	Mean force reading*	Range of tuber force readings
1.065	1	9.11	8.8–9.5
1.075	5	8.48	7.5–9.5
1.080	3	8.87	8.0–9.8
1.085	3	8.32	7.8–9.3
1.090	3	8.85	8.5–9.3
1.095	4	8.97	8.5–9.0
1.100	4	8.41	8.0–9.0
1.105	4	8.23	7.8–9.0
1.110	1	7.86	7.5–8.3
Total	28	8.57	Av. 8.0–9.2

* These values are empirical only, but are quite suitable for comparative purposes.

The specific gravity-penetration force correlation coefficient was computed and found to be 0.226. This figure does not represent significance.

Discussion

The penetration force, in so far as determined by this experiment, has no close relationship with tuber density. Apparently, the flesh firmness of potato tubers is dependent upon internal factors other than, and presumably not related to, dry matter content. This result is in accord with that of Turnquist (11) whose brief report in 1948 represents the only published record of a test of this nature that has been noted by the authors. Dallyn (5) in an unpublished 1947 report, recorded similar findings, but both Dallyn and Turnquist determined that there were significant differences in tuber flesh firmness between varieties. The latter also found a difference due to locations and a significant interaction between locations and varieties.

Because of the direct or the indirect relationship that is suggested by the fact that varieties themselves exhibit definite differences in tuber firmness, it is suggested that further penetration experimental work be undertaken. There is some possibility that a relationship can be shown to exist between potato storage adaptability and flesh firmness.

EXPERIMENT 2 (Electrical Resistance Trials)

Since dry matter and specific gravity are positively correlated an inverse relationship can be postulated—one between moisture content and specific gravity. A widely used method of measuring the moisture content of cereal grains is by grinding them and subjecting the finely divided material to a test for electrical conductivity. Similar means are used for determining moisture content of dehydrated fruit and vegetable stock. It was decided to attempt a similar test upon uniform sections of fresh potato tubers.

Before deciding upon what constitutes a uniform tuber section, the structure and composition of a typical tuber must be considered. Chatfield and Adams (3) give a variation of 66.0 per cent to 85.2 per cent for tuber moisture content, with a mean of 77.8 per cent. Ash content varies from 0.5 per cent to 1.9 per cent with a mean of 1.0 per cent. Many of the ash constituents are in non-ionizable form and hence have poor electrical conductivity, and for this reason the resistance to the passage of electrical current, rather than the conductivity, was assumed to be the more practical measurement.

An instrument used for measuring electrical resistance is the ohmeter. It is compact and relatively inexpensive. If the ohmeter method of measuring such resistance could be shown to have value, it would be simple and rapid.

Since the potato tuber is a modified, very much thickened and shortened stem, with few or many nodes, and with definite layers of tissue somewhat corresponding to those of normal stems, it can be assumed that the tuber composition is not homogeneous. This lack of homogeneity is shown in Figure 2.

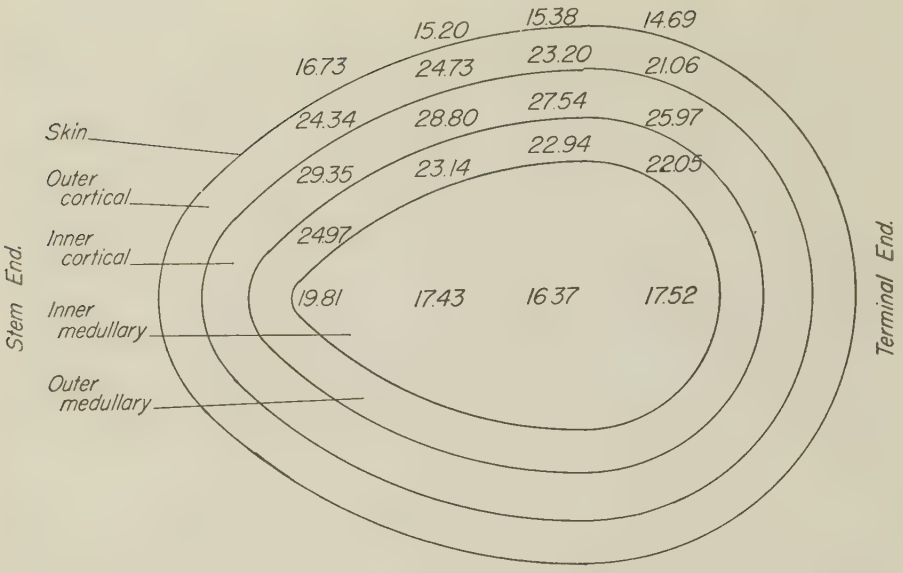

FIGURE 2. Variation in percentage of dry matter from samples of 20 tubers. (After Jackson and Glynne (8))

This figure shows that dry matter varies from the stem end to the terminal end, as well as within the several regions. Thus, skin and inner medullary (pith) regions are relatively low in dry matter while the cortical regions are relatively high. The outer medullary area (vascular tissue) is intermediate in dry matter content. From the above it will be seen that a flesh sample must be chosen carefully if the measurements are to represent the whole tuber.

While divisions into quarters or eighths and selecting diagonally opposite sectors will give the truest representation of a tuber (8), this is not feasible for the resistance measurements since the mass to be measured must itself be easily measurable, and of uniform diameter. It was therefore decided to take diagonal cores from the tubers for the work reported here.

Materials and Methods

The cores of tubers of known specific gravity were taken from ten different varieties, and as in Experiment 1, no attempt was made to keep the varieties separate. Rather, care was taken to secure specimens showing a wide range of tuber density, whatever the variety. The apparatus was set up as illustrated in Figure 3.

A Simpson ohmeter was used. The apparatus is explained in the diagram. The waxed paper strip was used between the baseboard and the meter-stick to prevent wetting the board, which would reduce resistance readings. The ohmeter anode was fixed at the 10 mm. mark and sections from tubers were removed by means of a No. 4 cork borer. Tuber eyes were avoided, and all borings were taken so that the section length was equal to the mean diameter of the tuber. This measure was calculated by

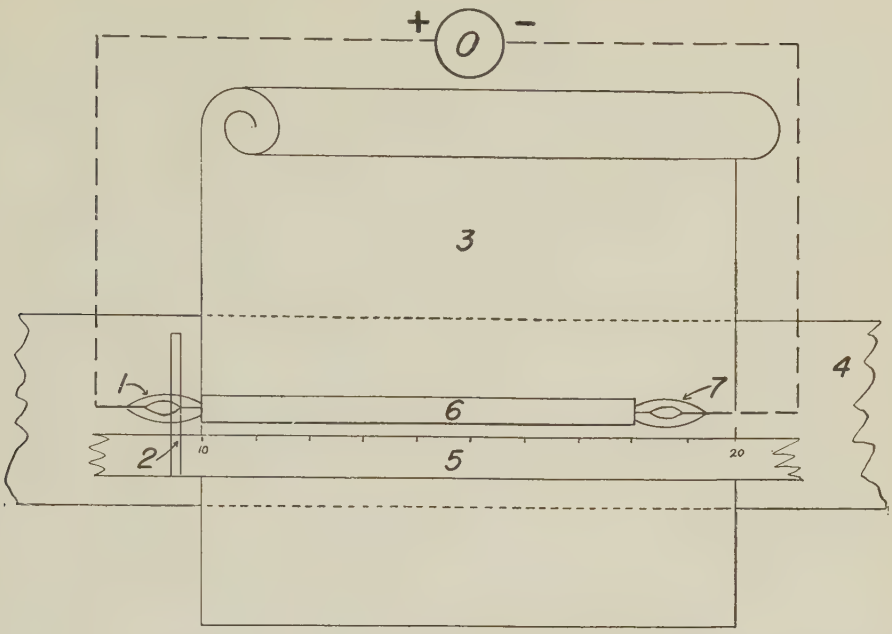

FIGURE 3. Arrangement of apparatus for measuring resistance in potato tubers.

taking the average of the length, breadth and depth. The skin at the core ends was peeled away before resistance readings were taken.

The section was laid beside the measure on the waxed paper and with one end touching the fixed anode terminal. When the cathode was applied to the other end the resistance in ohms was read from the ohmeter and the section length was read from the measure. The waxed paper strip was moved after each measurement to ensure that the new section rested upon dry paper.

Results

The specific gravity classes, number of readings, average resistance in 1,000 ohms per linear centimetre of section and the range of resistance readings appear in Table 2.

Casual examination of these data presents no apparent trend in any direction, and this is borne out by the correlation coefficient of specific gravity/resistance, which was 0.008, or negligible.

Discussion

From the data presented herein, no association between specific gravity (tuber density) and electrical resistance is indicated. This is in spite of apparently logical reasoning that would suggest such an association. The diversity of the dry matter content within any tuber, as shown in

TABLE 2. ELECTRICAL RESISTANCE OF POTATO SECTIONS OF KNOWN DENSITY

Specific gravity classes	No. of readings	Average resistance (in 1000 ohms per cm.)*	Range of resistance
1.060	2	7.80	6.9–8.7
1.065	2	6.15	5.8–6.5
1.070	5	6.34	5.5–6.5
1.075	7	6.71	4.3–8.4
1.080	8	6.16	5.1–8.1
1.085	6	5.54	5.1–6.1
1.090	10	5.80	5.4–6.8
1.095	7	5.90	5.2–6.8
1.100	5	5.68	4.6–6.7
1.105	4	6.63	6.2–7.0
1.110	3	6.23	4.9–7.5
Total	59	Av. 6.27	

* Sections of variable length but all were 8.2 mm. in diameter.

Figure 2, indicates the difficulty of securing a representative tuber portion by the core method. Possibly if the resistance of the whole tuber could be measured, a positive relationship between the two characters might be demonstrated but since no two tubers are exactly the same size and shape this would necessitate maceration of the tuber. If this were done, the test would be of little practical use or significance.

SUMMARY

1. The desirability of more satisfactory technique for measuring tuber density in Irish potatoes is discussed. Tubers of several varieties whose density has been calculated by the brine immersion method were subjected to penetration force and electrical resistance tests.

2. Measurement of tuber quality by means of a fruit maturity gauge (fitted with a 5 mm. plunger), showed a specific gravity/penetration force correlation of $r = 0.226$, and this was not significant. A total of 196 penetration force readings were made.

3. Sections from 59 tubers, taken in such a way as to be as representative as possible of internal composition, were used in electrical resistance measurements. An ohmeter was used and readings were expressed in 1,000 ohms per cm. length of core. A correlation $r = 0.008$ showed no indication of a relationship between tuber density and electrical resistance.

ACKNOWLEDGMENTS

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A STUDY OF SOME SEED-BORNE DISEASES OF CEREALS IN CANADA

I. COMPARISON OF SEED TESTING METHODS[1]

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INTRODUCTION

The recent expansion of the seed-growing industry in Canada has increased the demand among those engaged in the seed trade for up-to-date information concerning germinability, disease, and treatment of seed. It has been recognized, for instance, that the standard germination test on blotters is inadequate because (1) it does not give a uniformly accurate index of the percentage of healthy seedlings that may be expected from a seed stock when sown in the field; (2) because it does not reveal the nature and importance of many of the defects present in or on the seed, and (3) because it does not show the extent to which a lot of seed will benefit from treatment.

A comprehensive study of three aspects of the seed-borne disease problem was undertaken by the Dominion Laboratory of Plant Pathology at Winnipeg, at Saskatoon, and at Edmonton. The study included, *first*, a comparison of methods used by these laboratories for testing cereal seed; *second*, a survey of the most common defects of cereal seed; and, *third*, a comparison of germinations and yields obtained by planting seed with different percentages of infected kernels, together with a study of the effect of weeds in experimental plots on the gain in stand and yield following seed treatment.

The results of co-operative experiments on these subjects are to be presented in serial fashion, the present paper being the first of the series.

This section of the study describes and compares several laboratory and greenhouse methods of testing cereal seed for germinability and for the seed-borne organisms (except smut fungi) which affect seedling development and yield of the mature plant. A comparison of these methods is made with respect to: (1) uniformity of results, when they were used by different investigators; (2) their reliability, when they were used in an attempt to forecast how seed lots will germinate and yield in the field, and how they will respond to seed treatment; (3) their usefulness in indicating the condition of the seed.

The data are presented mostly in the form of correlations between the results of tests with 90 samples of seed in 1942-43, and with 12 samples in 1943-44. The 90 samples of seed used in 1942-43 included wheat, oats and barley from Manitoba, Saskatchewan and Alberta—10 samples of each crop from each province—and they were taken at random from seed lots to be sown by farmers in those provinces in 1943. The 12 farm samples used in 1943-44 (also wheat, oats and barley) were selected especially to represent healthy, diseased, and frosted seed.

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COMPARISON OF SOIL AND INCUBATION TESTS

Methods

The non-sterile soil test described by Machacek and Wallace (2), and the incubation test described by Simmonds and Mead (3), were compared at all three laboratories. Briefly, the nature of the two tests was as follows:

In the soil test, two 100-kernel aliquots (one treated with Ceresan—5 per cent ethyl mercury phosphate—and the other left untreated) from each seed lot were sown in adjacent rows in a large bed of non-sterile soil in the greenhouse. After a growing period of 10 days at approximately 20° C., the seedlings were taken from the soil, counted, and examined individually for abnormalities or lesions on the stems and leaves. This examination showed the percentage of normal and abnormal seedlings and the percentage of seedlings attacked by seed-borne, root-rotting and leaf-spotting fungi, such as *Helminthosporium sativum* P. K. & B., *H. teres* Sacc., *H. avenae* Eidam, *Septoria nodorum* Berk., and *Fusarium* spp. In addition, the test showed the degree to which each seed lot was improved by treatment with Ceresan. Certain difficulties were recognized in conducting the soil test. These included differences in the soil, and variations in watering and temperature. The first two difficulties could not be overcome, whereas the third difficulty, maintenance of a uniform temperature, could be overcome only to a limited extent, as adequate greenhouse temperature control equipment was lacking.

In the incubation test, untreated seed was plated on moist filter paper in Petri dishes, 25 seeds to a dish, and the cultures were held constantly at 24° C. for four days. The seeds were then examined directly through a low-power binocular microscope, this examination providing data relating to the amount of lesioning of seedlings, seed contamination and decay by such fungi as *Helminthosporium* spp. and *Fusarium* spp., as well as data regarding percentages of normally and abnormally germinating seeds. The meanings given to normal germination and abnormal germination were of the sense used by the seed testing laboratories of the Canada (Department of Agriculture) Production Service (1). According to the rules laid down for seed testing, abnormal germination or abnormal sprouts means seedlings with improperly developed shoots or roots. Among the abnormalities recognized are: watery or glassy, coiled, twisted, swollen, prematurely split, or extremely spindly shoots; stunted or swollen roots, or roots lacking normal growing points or root hairs.

The authors did not have an opportunity to make a joint study of seedling material before the experiments were started. This circumstance may account for some of the disagreements appearing among the experimental results given below.

Comparison of Data on Germination

The recorded data on normal and abnormal germination and lesioning from untreated seed sown at the three laboratories are summarized in Table 1. The data given are averages for 30 samples each of wheat, oats and barley, portions of the same samples of each crop having been tested at each laboratory.

TABLE 1.—COMPARISON OF AVERAGE DATA OBTAINED BY TWO SEED-TESTING METHODS (SOIL TEST AND INCUBATION TEST) AT THREE LABORATORIES

Data compared	Crop	Method	Testing laboratory		
			Winnipeg	Saskatoon	Edmonton
			%	%	%
Normal germination	Wheat	Soil	64.6	81.8	73.6
		Incubation	89.1	87.0	93.2
	Oats	Soil	60.8	79.7	75.4
		Incubation	70.8	51.2	57.9
	Barley	Soil	81.8	89.2	84.1
		Incubation	86.2	63.4	61.8
Abnormal germination	Wheat	Soil	10.7	1.5	5.1
		Incubation	4.7	8.7	1.0
	Oats	Soil	8.1	2.1	11.1
		Incubation	3.5	28.4	9.3
	Barley	Soil	4.9	1.3	2.3
		Incubation	2.3	9.5	4.8
Lesioning	Wheat	Soil	3.3	1.3	9.7
		Incubation	2.5	1.3	—[1]
	Oats	Soil	4.7	0.7	3.2
		Incubation	3.7	0.2	—
	Barley	Soil	6.2	3.2	8.3
		Incubation	1.8	4.0	—

[1] Lesioning in the incubation test was not recorded at Edmonton.

The data in Table 1 indicate that there was considerable variation among the readings obtained by the two seed-testing methods at the three laboratories. Normal germination, for instance, tended to be higher in all three crops in the incubation test at Winnipeg than in the soil test. In contrast, at Saskatoon and Edmonton such a trend was observed only in wheat, but there was an opposite trend in oats and barley. Abnormal germination at Winnipeg was consistently higher in the soil test than in the incubation test, at Saskatoon it tended to be higher in the incubation test, and at Edmonton it was variable. Data on lesioning were incomplete, no definite trend being observed.

The experimental data obtained during this comparison of testing methods were subjected to analyses of correlation. The numerous coefficients of correlation thereby obtained are tabulated in Tables 2, 3, 4, 5, 6, and 7. Those coefficients applying to normal and abnormal germination are given in Tables 2, 3, and 4; those applying to lesioning are given in Tables 5, 6, and 7.

As Table 2 shows, fairly good agreement between the two tests, when data on normal germination were correlated, was obtained for oats at Winnipeg, for wheat at Saskatoon, and for wheat and oats at Edmonton. Otherwise there was poor agreement. In the case of abnormal germination, correlation coefficients were either low or negative, thus indicating very poor agreement between the two sets of data.

When the data from the soil tests made at the three laboratories were correlated, it was found (Table 3) that agreement was good in the case of normal germination, but fair or poor in respect to abnormal germination.

The reason for the latter disagreement is not known. It is suggested that the three interpretations of the class "abnormal germination" did not coincide.

TABLE 2.—CORRELATIONS OF DATA ON NORMAL AND ABNORMAL GERMINATION IN THE SOIL AND THE INCUBATION TEST

Laboratory	Coefficients of correlation					
	Normal germination			Abnormal germination		
	Wheat	Oats	Barley	Wheat	Oats	Barley
Winnipeg	0.183	0.646	0.273	0.073	−0.250	0.217
Saskatoon	0.610	0.265	0.244	0.000	−0.002	0.137
Edmonton	0.405	0.629	0.136	−0.137	−0.254	0.150

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

TABLE 3.—CORRELATIONS OF DATA ON NORMAL AND ABNORMAL GERMINATION OBTAINED FROM SOIL TESTS AT THREE LABORATORIES

Laboratories compared	Coefficients of correlation					
	Normal germination			Abnormal germination		
	Wheat	Oats	Barley	Wheat	Oats	Barley
Winnipeg-Saskatoon	0.805	0.837	0.832	−0.205	0.612	0.055
Winnipeg-Edmonton	0.639	0.919	0.585	0.422	0.474	0.105
Saskatoon-Edmonton	0.588	0.966	0.462	0.202	0.118	0.182

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

Agreement between laboratories on normal germination in the incubation test was good, except in the Winnipeg-Saskatoon and Saskatoon-Edmonton comparisons with oats (Table 4). Correlations between the data on abnormal germination was low in seven out of nine comparisons, the coefficients being significant only in the Saskatoon-Edmonton comparison for oats and in the Winnipeg-Edmonton comparison for barley.

TABLE 4.—CORRELATIONS OF DATA ON NORMAL AND ABNORMAL GERMINATION OBTAINED IN INCUBATION TESTS AT THREE LABORATORIES

Laboratories compared	Coefficients of correlation					
	Normal germination			Abnormal germination		
	Wheat	Oats	Barley	Wheat	Oats	Barley
Winnipeg-Saskatoon	0.933	0.107	0.691	0.000	−0.287	0.065
Winnipeg-Edmonton	0.488	0.456	0.606	0.241	−0.133	0.478
Saskatoon-Edmonton	0.494	0.001	0.819	0.105	0.477	0.066

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

Comparison of Data on Lesioning

The percentage of seedlings bearing lesions on the coleoptile or roots was recorded at the time germination was determined. Data concerning lesioning in the incubation test, however, were obtained at only two laboratories, Winnipeg and Saskatoon.

It was found that there was good agreement between the two tests on lesioning for wheat at Saskatoon, for oats at Winnipeg, and for barley at both laboratories, and that there was poor agreement for wheat at Winnipeg, and for oats at Saskatoon (Table 5).

TABLE 5.—CORRELATIONS OF DATA ON LESIONING FROM SOIL AND INCUBATION TESTS AT TWO LABORATORIES

Laboratory	Coefficients of correlation		
	Wheat	Oats	Barley
Winnipeg	0.068	0.471	0.784
Saskatoon	0.910	−0.181	0.939

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

Correlation between the results on lesioning in soil at the three laboratories was high on wheat, moderate but significant on barley, and low or negative on oats (Table 6).

TABLE 6.—CORRELATIONS OF DATA ON LESIONING FROM SOIL TESTS AT THREE LABORATORIES

Laboratories compared	Coefficients of correlation		
	Wheat	Oats	Barley
Winnipeg-Saskatoon	0.898	−0.109	0.643
Winnipeg-Edmonton	0.782	0.211	0.397
Saskatoon-Edmonton	0.704	−0.250	0.435

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

In the incubation tests made at the Winnipeg and Saskatoon laboratories, there was good agreement on lesioning of wheat and barley, but no agreement in the case of oats (Table 7).

TABLE 7.—CORRELATIONS OF DATA ON LESIONING FROM INCUBATION TESTS AT TWO LABORATORIES

Laboratories compared	Coefficients of correlation		
	Wheat	Oats	Barley
Winnipeg-Saskatoon	0.660	−0.105	0.939

Significance: 5 per cent, 0.361; 1 per cent, 0.436.

Comparison of Laboratory Data with Those Obtained Under Field Conditions

Eighteen representative samples of seed, six each of wheat, oats and barley, were sown in the field for the purpose of obtaining a comparison of field data with data obtained in the greenhouse (soil test) and in the laboratory (incubation test). After these data were obtained, they were combined and correlated with the combined data from the soil test and the combined data from the incubation test. The correlation coefficients obtained with these data are shown in Table 8. It may be seen that there was better agreement between the soil test and the field test than between the incubation test and the field test at all three laboratories.

TABLE 8.—A COMPARISON OF NORMAL GERMINATIONS IN THE SOIL TEST AND THE INCUBATION TEST WITH THAT OBTAINED IN THE FIELD

Laboratory	Coefficients of correlation	
	Soil test and field	Incubation test and field
Winnipeg	0.921	0.593
Saskatoon	0.855	0.287
Edmonton	0.681	0.073

Significance: 5 per cent, 0.468; 1 per cent, 0.590.

Comparison of Seed Treatment Data

In order to determine whether the gain in germination, obtained in the soil test following treatment of the seed with Ceresan (5 per cent ethyl mercury phosphate), is reflected by a gain in yield under field conditions, 12 samples of seed were sown, treated and untreated, in the greenhouse and field at each of the three stations concerned with this investigation. A correlation of the changes in germination with the changes in yield gave the coefficients shown in Table 9. According to these coefficients, the gain in normal germination in the soil test had little or no relation to the yield under field conditions.

TABLE 9.—CORRELATION OF THE CHANGES INDUCED BY SEED TREATMENT IN THE PERCENTAGE OF NORMAL SEEDLINGS IN THE SOIL TEST WITH THE CHANGE IN YIELD INDUCED BY SEED TREATMENT UNDER FIELD CONDITIONS

Laboratory data from:	Field data from:	
	Manitoba	Saskatchewan
Winnipeg	0.230	0.274
Saskatoon	0.143	0.331
Edmonton	0.450	−0.200

Significance: 5 per cent, 0.707; 1 per cent, 0.834.

Summary

An examination of data on normal germination obtained from laboratory tests failed to show a consistent agreement between laboratories when they used the soil test and the incubation test on the same seed. This lack

of agreement could have arisen from an unfamiliarity of the investigators with one or both of the tests. When the data from the soil test alone were considered (Table 3), there was, for three cereals, a high correlation between percentages for normal germination obtained at the three laboratories. It was shown (Table 8) that these results agreed fairly closely with those from a field test, indicating that the soil test was reasonably reliable for the purpose of forecasting germination in the field. Agreement between the three laboratories was also fairly good, except on oats, when the incubation test was used to measure normal germination in the laboratory (Table 4), but this test did not appear to be consistently reliable as a means of indicating germination in the field (Table 8).

COMPARISON OF DATA FROM SOIL AND SAND TESTS IN PAPER BOXES

Methods

In further studies, non-sterile soil and sand were used to test 12 selected samples of wheat, oats, and barley. These tests were run concurrently at the three laboratories, under conditions as similar as possible. The soil and washed coarse sand were placed in separate cardboard boxes ($4\frac{1}{2}$ in $\times$ $4\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. and with perforated bottoms) to the depth of one-half inch. One hundred seeds were sown and spaced evenly in each box on the basal layer of the medium and then were covered with another half-inch layer of the same medium. The boxes were planted in quadruplicate, arranged at random on metal trays, and watered uniformly then, and when necessary later. These tests were carried on for 10 days at about 20° C., and after this interval the seedlings were removed from the medium to be classified.

Comparison of Data on Germination and on Lesioning

The data on normal and abnormal germination obtained from wheat, oats, and barley sown in boxes, were combined and these combined data, together with similar data on lesioning, are presented in Tables 10, 11, 12, and 13. Table 10 shows the average percentages for normal germination, abnormal germination, and lesioning obtained at the three laboratories by the two tests. Tables 11, 12, and 13 show the correlation coefficients obtained after a statistical comparison was made.

TABLE 10.—AVERAGE PERCENTAGES OF NORMAL GERMINATION, ABNORMAL GERMINATION, AND OF LESIONING FOR 12 SAMPLES OF CEREAL SEED[1] SOWN IN SOIL OR SAND IN CARDBOARD BOXES

Data compared	Kind of test	Laboratory		
		Winnipeg	Saskatoon	Edmonton
		%	%	%
Normal germination	Soil	56.8	60.2	74.5
	Sand	48.0	59.5	72.0
Abnormal germination	Soil	13.0	11.6	4.8
	Sand	9.5	6.2	4.5
Lesioning	Soil	8.8	8.2	7.2
	Sand	27.0	19.4	10.8

[1] Three of these samples were damaged by frost.

The data shown in Table 10 indicate a considerable difference in the amount of abnormal germination and lesioning obtained by the two tests, and also a considerable variation in the normal germination noted by the three laboratories.

Correlations of test data showed that, at each of the three laboratories, there was a close relationship between the data obtained by the two tests (soil and sand) with respect to normal germination and lesioning. For lesioning this close relation held good only for Winnipeg and Edmonton.

TABLE 11.—CORRELATIONS OF DATA ON NORMAL GERMINATION, ABNORMAL GERMINATION, AND LESIONING OBTAINED IN SOIL-BOX AND SAND-BOX TESTS

Laboratory	Coefficients of correlation		
	Normal germination	Abnormal germination	Lesioning
Winnipeg	0.605	0.857	0.758
Saskatoon	0.778	0.345	0.924
Edmonton	0.883	0.978	0.698

Significance: 5 per cent, 0.576; 1 per cent, 0.708.

When soil was used as a testing medium, there was good agreement between laboratories in the amount of normal germination and fair agreement in respect to lesioning and abnormal germination (Table 12).

TABLE 12.—CORRELATIONS OF DATA REGARDING NORMAL AND ABNORMAL GERMINATION AND LESIONING IN SOIL-BOX TESTS

Laboratory data compared	Coefficients of correlation		
	Normal germination	Abnormal germination	Lesioning
Winnipeg-Saskatoon	0.943	0.579	0.371
Winnipeg-Edmonton	0.881	0.756	0.647
Saskatoon-Edmonton	0.945	0.481	0.652

Significance: 5 per cent, 0.576; 1 per cent, 0.708.

In the sand tests, better agreement between laboratories was obtained in respect to lesioning than in respect to germination, although the coefficients of correlation in all cases were significant (Table 13).

TABLE 13.—CORRELATIONS OF DATA REGARDING NORMAL AND ABNORMAL GERMINATION AND LESIONING IN SAND-BOX TESTS

Laboratory data compared	Coefficients of correlation		
	Normal germination	Abnormal germination	Lesioning
Winnipeg-Saskatoon	0.840	0.636	0.904
Winnipeg-Edmonton	0.672	0.878	0.848
Saskatoon-Edmonton	0.640	0.753	0.976

Significance: 5 per cent, 0.576; 1 per cent, 0.708.

Comparison of Box Data with Field Data

Seed of the 12 samples which had been tested in soil and sand in boxes in the greenhouse were also used in field tests. The purpose of these field tests was to compare the response of the samples (increase in normal germination) to treatment with Ceresan in the boxes under laboratory conditions with the response (effect on yield) under field conditions. The coefficients of correlation obtained in comparisons made at three laboratories are shown in Table 14.

TABLE 14.—COEFFICIENTS OF CORRELATION FOR A COMPARISON OF THE EFFECT OF SEED TREATMENT ON NORMAL GERMINATION IN SOIL AND SAND-BOX TESTS AND ON YIELD IN FIELD TESTS AT THREE LABORATORIES

Laboratory test	Field data from		
	Winnipeg	Saskatoon	Edmonton
Soil in boxes	0.300	−0.198	−0.262
Sand in boxes	−0.148	−0.290	−0.167

Significance: 5 per cent, 0.576; 1 per cent, 0.708.

These results show that there was either a low positive correlation, or a negative correlation, between normal germination in laboratory tests and the yield from field tests. It may be assumed, therefore, that increases in normal germination obtainable in box tests following treatment of the seed would not be necessarily an indication of a probable beneficial effect of seed treatment on yield.

Summary

Correlations of the data from soil-box and sand-box tests indicate that fairly good agreement was reached with respect to normal germination and lesioning when each laboratory ran parallel tests. The results were sufficiently close to suggest that either medium could be used in testing seed for germination and the presence of certain kinds of disease, such as rootrot, seedling blight, or seed rotting. There was no indication, however, that the response in these laboratory tests of a seed sample to seed treatment, as measured by germinability, would be evident in a test of yield in the field.

DISCUSSION

Previous experience of the authors has shown that the standard germination test used for cereals is unsuitable for the detection of their seed-borne diseases. It seemed apparent that more information about a seed sample could be secured by using a different type of test and this view is supported by the results of the experiments described above. In the present experiments, soil in a large bed or in cardboard boxes, sand in cardboard boxes, and moist filter paper in Petri dishes, were substituted for the germination blotters used in the standard germination test for wheat, and notes were taken on normal and abnormal germination, lesioning, seedling blight, seed decay, and response to seed treatment.

A study of correlation between the data obtained by the various tests showed that, when measuring normal and abnormal germination, each of the three investigators obtained in some cases quite different results from the greenhouse soil test than from the incubation test. This lack of uniformity suggests that one or both of these tests have weaknesses which affect their usefulness. When, however, the data from the greenhouse soil test and the incubation test were examined separately, it was found that agreement on normal germination between laboratories was better in the former test; but, in the matter of abnormal germination, agreement was poor in the soil test, and very poor in the incubation test. In respect to lesioning, agreement was good in both tests for wheat and barley, but very poor for oats.

From these results, it appears that the two tests were imperfect in certain respects, a few of which are as follows: (1) lesioning in the soil test was somewhat erratic, being affected by differences in soil and by variations in watering and temperature; (2) some fungi, such as *Helminthosporium teres*, did not regularly cause basal lesioning of plants in soil, and an extra test, on agar, has to be conducted to demonstrate their presence; (3) oats grew very poorly on moist filter paper in Petri dishes; and (4) moulds tended to spread in the Petri dishes.

The usefulness of the soil test was established in predicting the percentage of normal seedlings that may be expected from seed sown in the field, for, when a comparison was made of data from laboratory and field tests, it was found that, at all of the three laboratories, the results from greenhouse soil tests agreed very well with those from field tests. On the other hand, agreement of the incubation test data with field data was very poor. In addition, the soil test showed that certain samples, if treated with Ceresan, improved in normal germination, but this improvement was not followed consistently by an improvement in yield in field plot tests. Actually, very little relation was found between the results of the greenhouse tests and those of the field tests in respect to yield.

Certain criticisms of the greenhouse soil test and the incubation test with respect to applicability to laboratory procedure, ease and speed of operation, and freedom from contamination, were made by one or more of the authors. The possibility of using large beds of soil in a seed testing laboratory was questioned. Although this requirement (large beds of soil in a greenhouse) cannot be fulfilled in the existing official seed testing laboratories, it might be in future laboratories. There were indications that fungus contamination of seedlings could come from the soil. One of the authors felt that the incubation test was tedious and slow, and all of them agreed that moulds could contaminate the Petri dishes and affect adversely the germination of the seed. Favourable comments on these tests included the recognition that a large number of seed samples could be rapidly handled in the greenhouse soil test, which was said to be a natural test and one more closely related to actual growing conditions than an *in vitro* test or a test on blotters. The incubation test was recognized as one readily applicable to laboratory use and one in which the temperature could be controlled easily.

The laboratory tests with non-sterile soil, and washed non-sterile sand in cardboard boxes, yielded results on normal germination and lesioning for which a high degree of correlation was obtained, that is, the results were very similar for parallel tests in soil and sand at each laboratory. Furthermore, comparisons between these data showed good agreement between the three laboratories. The main criticisms of soil and sand in boxes were that it was difficult to keep them moist, and that, in the sand, fungi tended to spread from diseased seedlings to healthy ones.

As the best agreement between laboratories was obtained by the use of non-sterile soil or washed sand in cardboard boxes, and because this technique could be adapted to laboratory procedure (sand in boxes is used regularly for the germination of barley and oats), it is suggested that this method, with some modifications in temperature and moisture control, would be suitable for testing seed for seed-borne fungi. This conclusion is supported by the fact that, in some European laboratories, crushed brick is used as a germinating medium in seed-borne disease studies.

SUMMARY

In 1942-43, ninety samples of wheat, oats and barley were tested for germination and disease in non-sterile soil in the greenhouse and on moist filter paper in Petri dishes in a series of co-operative tests conducted at the Dominion Laboratories of Plant Pathology at Winnipeg, Saskatoon and Edmonton. Correlation studies of the data from these tests showed that the best agreement was obtained in the soil test. Both tests had commendable features, but they also had some faults which made them unsuitable for use or impracticable at the present time.

In a second series of tests, made in 1943-44, twelve samples of cereal seed were tested in non-sterile soil and in washed non-sterile sand contained in cardboard boxes. Agreement between the results of this limited series of tests from the three laboratories was much better than in the first series. Because of this improved agreement, and because this technique could be adapted to ordinary laboratory procedure, the suggestion is made that the latter type of test would be suitable for seed-borne disease studies, provided a standard medium was used.

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THE WHOLE EMBRYO METHOD OF TESTING BARLEY FOR LOOSE SMUT AS A ROUTINE TEST[1]

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The method commonly used to determine the presence of loose smut, caused by *Ustilago nuda* (Jens.) K. & S., in barley seed is to plant a sample of the seed and grow the plants until they come into head. The total number of healthy and of smutted heads are counted and the percentage infection is computed. Simmonds (1) showed that the presence of the mycelium of the fungus in the embryos of barley seeds may be detected by separating out the embryos and examining them with a microscope. Provided that, for any given seed lot of barley, the percentage of infected embryos is closely correlated with the percentage of smutted plants that is produced by the seed, an examination of the embryos could be substituted with advantage for the usual growth test as a means of determining the amount of loose smut that is likely to appear in a crop grown from the seed. The main advantages are that (*a*) the percentage of infected embryos present in a sample of barley seed may be determined much more quickly by the embryo test than by the growth test, and (*b*) no greenhouse or field plot space is required for the embryo test. If this test fulfils the purpose, it should be of considerable practical value to plant breeders and to those engaged in seed certification.

The present investigation was undertaken to ascertain whether or not the percentage infection, as determined by the embryo test, agrees closely with that obtained by growing a crop from the same seed stock.

MATERIALS AND METHODS

Most of the barley seed used in these experiments belonged to varieties which are in common use in Saskatchewan at the present time, or to varieties which have been grown to a considerable extent there in the past. However, the variety Montcalm predominated. Naturally-infected seed was secured in the first place from farmers and from experimental institutions, and infected samples were subsequently increased in experimental field plots.

Embryo tests were conducted by the Simmonds method (1), with minor changes in detail. Usually, all the embryos recovered from 500 seeds were examined, and, on the average, the number was approximately 475 embryos per sample.

Growth tests were conducted both in the greenhouse and in the field. In the former, the results were based usually on from one to two hundred plants. This number was much lower than is desirable, but it was limited by lack of space and poor light conditions that prevented some of the plants from producing heads. Field tests were conducted at two places in the province, Saskatoon and Indian Head. In the field tests ten eight-foot rows were devoted to each sample and about 80 plants matured heads in

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each row, making a total of approximately 800 plants at each place. Twenty-nine samples were sown at the former place and twenty-eight at the latter.

In the growth tests, all the heads affected with loose smut were collected and spores from each were germinated, in order to cull out any heads affected with false loose smut, caused by *Ustilago nigra* Tapke. Therefore, all data presented in this paper refer to heads known to be affected with *U. nuda*. The percentage infection in the different samples varied from 0 to 25, the average being 3 or 4 per cent.

COMPARISON OF PERCENTAGE INFECTION AS DETERMINED BY DIFFERENT TESTS

The results secured in the four different tests mentioned above are shown in Table 1. There was a high positive correlation between the percentages of infection determined by the visual examination of the embryos, on the one hand, and those determined by the several growth tests, on the other. The coefficient of correlation was over 0.97 in each case. The closeness of agreement between them is further illustrated by Figure 1.

TABLE 1.—THE PERCENTAGE INFECTION WITH LOOSE SMUT *(Ustilago nuda)*, IN THIRTY SAMPLES OF BARLEY SEED, AS DETERMINED BY FOUR DIFFERENT TESTS

Variety	Sample designation	Embryo test	Greenhouse test	Field tests	
				Saskatoon	Indian Head
Montcalm	705	1.4	0.7	1.6	—
Montcalm	707	0.0	0.0	0.1	0.0
Montcalm	708	2.0	0.0	—	2.9
Montcalm	710	0.2	1.4	1.1	0.4
Montcalm	711	1.6	4.7	1.4	1.7
Montcalm	712	4.4	6.0	3.5	3.4
Montcalm	713	4.7	3.6	4.2	4.1
Montcalm	715	1.0	0.0	1.0	1.6
Montcalm	716	3.6	4.2	2.3	2.9
Montcalm	717	4.9	4.7	3.1	3.5
Montcalm	719	4.7	4.7	3.7	3.7
Montcalm	720	3.1	4.0	2.5	3.1
Montcalm	Balcarres	0.4	1.0	0.5	0.3
Montcalm	Kelvington	3.2	3.0	2.5	1.1
Montcalm	Melfort	1.3	3.0	0.5	0.6
Montcalm	Saltcoats	0.8	1.0	0.6	0.5
Montcalm	Tisdale	0.2	0.0	0.2	0.1
Montcalm	Codette	0.0	0.0	0.2	0.6
Plush	1947	1.2	1.0	1.0	0.7
Plush	1948	0.3	0.0	0.4	0.4
Velvon	Scott	0.0	0.0	0.0	0.1
Titan	Scott	0.0	0.0	0.1	0.0
Glacier	Border row	10.7	10.1	11.9	10.7
Glacier	Row 12	7.0	7.0	7.1	7.8
Glacier	Sealer 2	6.9	—	5.8	6.6
Multiple cross	17 per cent	24.4	22.8	19.8	—
Multiple cross	24 per cent	3.5	3.4	2.7	3.1
Multiple cross	2 per cent	0.2	1.2	0.6	0.3
Newal	Indian Head	6.2	4.2	7.0	6.6
Rex	Saskatoon	18.2	18.7	18.9	23.3

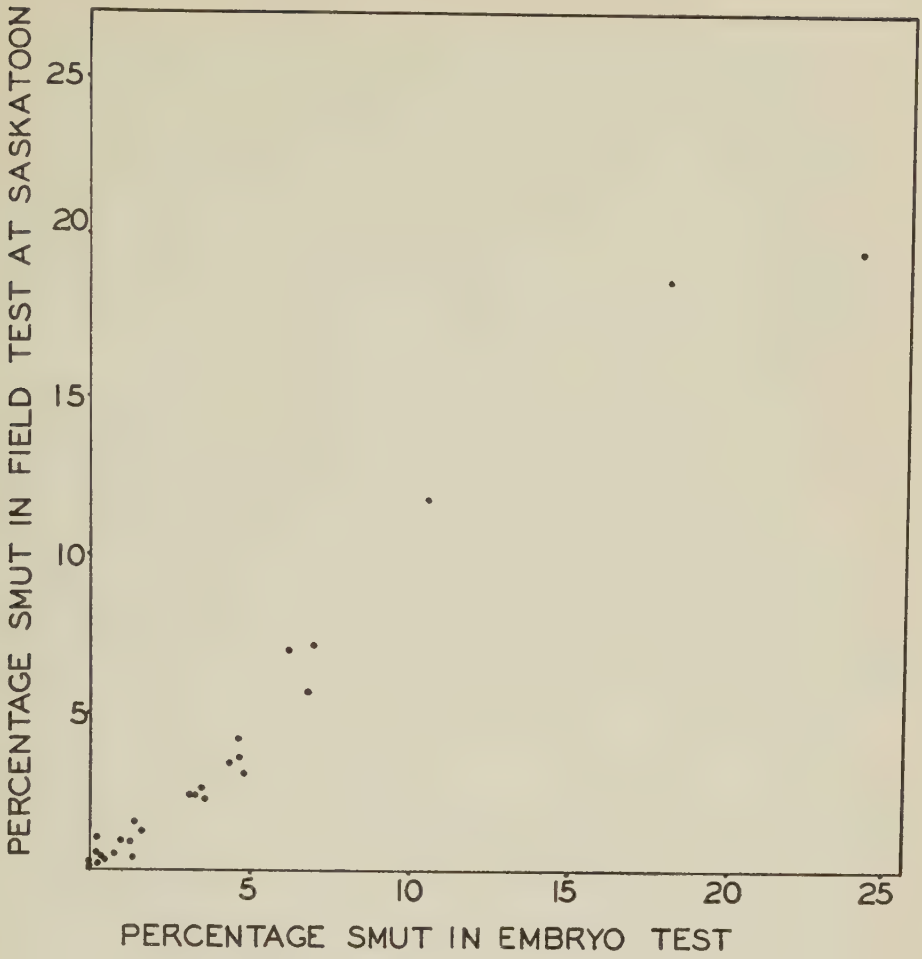

FIGURE 1. Graph showing the correlation between the percentage infection of 29 samples of barley seed, subjected to the embryo test, and the percentage infection arising in a growth test of the same samples conducted in the field at Saskatoon.

The average percentage infection found in the growth tests was practically the same as that determined by the embryo tests. In the 29 samples which were grown in the greenhouse, the average infection according to the embryo test was 3.77 per cent. In the growth test, it was 3.81 per cent. In 29 samples grown in the field at Saskatoon, the corresponding figures were 3.93 per cent and 3.60 per cent, and, for those grown at Indian Head, 3.22 per cent and 3.21 per cent. Both in the greenhouse and at Indian Head, where good conditions for germination prevailed, these percentages agree almost exactly. At Saskatoon, the soil in the field was so dry that a considerable portion of the seed did not germinate for several weeks after it was sown. Under these conditions, the percentage infection was somewhat lower than the embryo test indicated—3.60 per cent compared with 3.93 per cent.

DISCUSSION

The experimental data presented above show that, with the barley varieties used in this investigation, microscopic examination of the embryos of the seed gives a very good indication of what percentage of infection with loose smut may be expected when a crop is grown under normal conditions from the same sample. This conclusion may not be true for certain hypersensitive varieties, such as Titan (4), but it is true for most of the varieties used when they are infected naturally rather than artificially. Thren (2) has shown that the injury to the embryos caused by artificial inoculation with dry spores of *U. nuda* may be reduced by using small proportions of viable spores diluted with relatively large proportions of spores killed by artificial means.

It is possible that, on the average, embryos infected with *U. nuda* are somewhat weaker than non-infected embryos. They sometimes appear to be smaller and somewhat deformed. The fact that the average infection under field conditions at Saskatoon, as reported above, was less than the average infection shown by the embryo test supports this assumption. However, the mortality of the infected embryos, in the greenhouse and in the field at Indian Head, was not much greater than that of the non-infected ones. This is proven by the fact that the average infection at heading time corresponded closely to the percentage of infected embryos. In his work with loose smut of wheat, Vanderwalle (3) reports that he found no correlation between the presence of the fungus in the seed and the germinative vigour of the seed.

There is no doubt that the embryo test will prove useful whenever it is desirable to ascertain how severely a sample of seed barley is infected with true loose smut. Plant breeders can quickly determine whether or not *U. nuda* is present in the embryos of special seed which they intend to use. Government seed laboratory officials can use it as a basis for deciding whether or not to pass certain lots of seed for certification or registration. However, if the limit of tolerance allowed for this disease is very low, the usefulness of the test may be diminished. At the present time, a maximum of one per cent of smutted heads is allowed in fields producing certified seed and only one-half of one per cent in fields producing registered seed. It is conceivable, then, that enough embryos might be examined to make the test of practical value as far as certified seed is concerned, but the number necessary in the case of registered seed might be too great to make the test feasible as a routine procedure. Table 2 shows how many embryos should be counted to give reasonable assurance that smut will be detected when the percentage infection is in the order of one per cent, and of one-half of one per cent.

According to these computations, if smut infection is present to the extent of one per cent, and a representative sample consisting of 600 embryos is examined, there are only two chances in a thousand of failing to detect the smut. However, if only one-half of one per cent of the seeds carry smut, and a sample consisting of 600 embryos is examined, there are about five chances in every hundred of failing to detect any smut.

Similar computations to those by which the figures in Table 2 were derived show that, if a stock of seed carried loose smut infection in 1 per

TABLE 2.—THEORETICAL PROBABILITIES OF NO SMUT APPEARING IN A GIVEN SAMPLE OF SPECIFIED SIZE, TAKEN FROM A POPULATION IN WHICH THE PERCENTAGE INFECTION IS ONE PER CENT, AND ONE IN WHICH IT IS ONE-HALF OF ONE PER CENT

Number of embryos in sample	Probability of no smut if infection is one per cent	Probability of no smut if infection is one-half of one per cent
100	0.3664*	0.6053
200	0.1343	0.3664
300	0.0492	0.2218
400	0.01803	0.1343
500	0.00661	0.0813
600	0.00242	0.0492
700	0.00089	0.02978
800	0.00033	0.01803
900	0.00012	0.01091
1000	0.00004	0.00661

* The first term of the expansion of $\left(\frac{99}{100} + \frac{1}{100}\right)^{100}$.

cent of the seeds, the examination of a sample consisting of 600 embryos would, in 38 per cent of the tests, result in the finding of more than 1 per cent, and the seed stock would be rejected when it should not be. However, very few seed stocks carry exactly one per cent of infected seeds and, the further the actual percentage is from the limit of tolerance (i.e. one per cent), the less likelihood would there be of making a wrong decision from the results of the embryo test. The same difficulty would arise in a growth test involving 600 plants.

At times, negative results from the embryo tests would be of considerable value. The entire absence of smut in a sample is highly significant, and shows that little or no infection exists in the seed stock from which the sample is taken.

In the production of either certified seed or registered seed, it is felt that the embryo test would provide a better criterion than the present method for deciding what barley seed should be passed for certification and what should be rejected on account of the presence of loose smut. The present method relies on field counts made in the standing crop from which the seed comes. In the first place, the loose smut seen in the field may be partly false loose smut (*U. nigra*). The only way to make certain whether it is true or false loose smut is to germinate the spores from a number of the diseased heads. In the second place, the percentage of heads found infected with true loose smut in the standing crop may or may not give a true picture of the percentage of infected embryos in the seed produced by that crop. If environmental conditions are specially favourable for infection when the crop comes into flower, there is likely to be considerably more infection in the seed than was present in the standing crop. On the other hand, if conditions are very unfavourable for infection during the period that the crop is in flower, the percentage of infected seeds may be considerably less than the percentage of infected heads in the standing crop. Several instances were recorded in 1948 and 1949 in which the percentage infection in field plots in Saskatchewan was several times as high as the percentage infection in the seed produced on those

plots. The embryo method of testing, as compared with the usual method, does not confuse false loose smut (*U. nigra*) with true loose smut (*U. nuda*), and it shows the amount of smut in the present generation, not the amount in the previous generation.

If the embryo test had been applied to the 30 samples dealt with in Table 1, and infection up to 1 per cent tolerated, then 19 of the samples would have been rejected and 11 passed for certification. In the field tests, 17 of these 19 samples showed over 1 per cent infection. Only two of the 11 samples produced over 1 per cent of infected plants. It is evident, then, that decisions relating to certification, based on these embryo tests, would have been correct 26 times out of 30, that is to say, if the percentages obtained in the growth tests were correct.

SUMMARY

The percentage infection with true loose smut, as found by a visual examination of the embryos of 30 samples of barley, is compared with the percentage infection shown in growth tests both in the greenhouse and in the field.

The agreement between the embryo test and the growth tests is very close, the coefficient of correlation being over 0.97 in each instance.

It is felt that the embryo test should prove valuable as a routine test, especially in connection with certain plant breeding work and the certification of seed barley.

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